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Technical Report ECOM-01698 11

LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

PROGRESS REPORT

by

L. Lesensky - M. Arium
C. McGeoch

DECEMBER 1968

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N J

Contract DA28-043-AMC-01698 (E)

SPONSORED BY: ADVANCED RESEARCH PROJECTS AGENCY
ARPA ORDER NO. 345

RAYTHEON COMPANY
MICROWAVE AND POWER TUBE DIVISION
Waltham, Massachusetts

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Technical Report ECOM-01698-11

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LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

Eleventh Quarterly Report
15 April 1968 to 15 July 1968

Report No. 11
Contract No. DA28-043-AMC-01698(E)
DA Project No. 7900-21-223-12-00

Prepared by
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Waltham, Massachusetts 02154

For

U. S. Army Electronics Command
Fort Monmouth, N. J. 07703

Sponsored by

Advanced Research Projects Agency
ARPA Order No. 345

ABSTRACT

Tests were continued on the effects of high current-density electron bombardment (0.75 A/cm^2) and of residual gases (O_2, N_2, and CO_2) on the secondary emission ratio (δ) in the Electron Bombardment Vehicle (EBV). Four samples were tested during the present report period, two anodized Be samples, one electron-beam evaporated aluminum-oxide on molybdenum sample and one naturally oxidized beryllium sample. δ_{max} was found to increase: 1) in all cases for O_2, and 2) in the case of anodized 300°A Be and natural oxide Be for N_2 and CO_2. The samples were bombarded at 0.15 A/cm^2 with the gas present at approximately 5×10^{-6} Torr pressure. Typical increases of δ_{max} were from 2.5 to 3.5.

The QKS1397 CFA test vehicle with an evaporated Al film on Cu cold cathode has continued to run successfully a total of 330 hours to date: the last 100 hours have been run without O_2 assistance.

The QKS1194 CFA test vehicle with an impregnated-tungsten cold cathode has run approximately 150 hours to date without thermal activation.

FOREWORD

Long-life cold cathode studies for crossed-field tubes are authorized by the United States Army Electronics Command, Fort Monmouth, New Jersey, under DA Project 7900-21-223-12-00. The work was prepared with the support of the Advanced Research Projects Agency under Order No. 345 and is conducted under the technical guidance of the U. S. Army Electronics Command, Fort Monmouth, New Jersey, 07703.

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1. INTRODUCTION

The objective of the present cold-cathode study program is to achieve long life cold-cathode performance for crossed-field amplifiers. This program is being performed for the United States Army Electronics Command, Fort Monmouth, New Jersey, under contract DA-28-043-AMC-01698(E).

In this study, selected cold cathode materials will be evaluated as to their secondary emission properties, their ability to withstand environmental factors expected in a crossed-field amplifier, and their crossed-field amplifier performance. Based on the above experimental information and pertinent theoretical calculations, a life prediction chart will be established for a number of cold cathode materials.

The program is divided into two concurrent phases, Phase A being concerned with the measurement of various pertinent properties of cold cathode materials outside of the tube environment, and Phase B involving the evaluation and life testing of selected cathodes in a crossed-field amplifier.

The first quarterly report of this contract (Technical Report ECOM 01698-1) contains a discussion of the objectives and plans for the over-all program. Quarterly Report No. 5 contains a description of the CFA test vehicles used in this program.

2. PHASE A - MATERIALS EVALUATION

2-1 Electron Bombardment Evaluation. During the present quarter, a number of samples were evaluated in the Electron Bombardment Vehicle (EBV). The effect on secondary emission ratio (δ) of high current-density electron bombardment (up to 0.75 A/cm^2) was measured as well as the recovery of δ with oxygen, nitrogen, and carbon dioxide.

These samples were:

a. A 300Å layer of BeO on Be (anodically oxidized), to a total of 140 hours (a continuation from the last quarter, when this sample ran for 37 hours).

b. Another anodically oxidized sample of 300Å BeO on Be, 49 hours.

c. Naturally oxidized Be sample, 58 hours.

d. A sample of 300Å electron-beam-evaporated Al_2O_3 on Mo.

Sample preparation during the present quarter consisted of:

a. Three silver-magnesium (Ag-Mg) samples for EBV evaluation were processed by thermal oxidation to achieve an optimum secondary-emission ratio. Three additional Ag-Mg samples (not thermally oxidized) are available for EBV testing.

b. Three beryllium-copper (Be-Cu) samples were optimally processed to oxidize the surface for high secondary-emission ratio. These and three other unprocessed ones are now available for EBV evaluation.

2.1.1 Anodized Be - 300Å - oxide layer

This sample, reported in the tenth quarterly, was run for an additional 103 hours (hrs 37 to 140) and the data is presented in Figure 1. During this time, the target was exposed to residual atmospheres of O_2 and N_2 at pressures of 5×10^{-6} Torr; the background pressure was always approximately 1×10^{-8} Torr. Bombardment levels of 0.75 A/cm^2 (15 ma) and 0.15 A/cm^2 (3 ma) were used. Maximum value of secondary-emission ratio (δ) varied from a low of 2.4 to a high of 3.9 during this period.

The data taken during the first 37 hours, reported in the previous quarterly, showed a positive response to O_2 at 1×10^{-5} Torr. Further evaluation showed a positive response to O_2 at the same pressure starting at hour 58. Continued bombardment of 0.75 A/cm^2 caused δ max to decrease to 3.2 after reaching a maximum of 3.9. Subsequent efforts to determine the restorative effects of N_2 were inconclusive. δ max remained between 2.8 and 3.0, with at most a small N_2 effect which was not reproducible. Rechecking the restorative effect of O_2 at hour 99 showed a negligible effect with δ max at $\sim$ 2.8. This may be interpreted to imply a deteriorated sample. However, a positive response to N_2 at hour 130.5 showed an increase of δ max from 2.4 to 2.85. It seems reasonable to suppose that the "condition" of the sample at that time was such that recovery with N_2 or O_2 would only be evident if δ max fell below 2.8 and that recovery would occur to a maximum value of δ max of 2.8.

2.1.2 Anodized Be - 300Å oxide layer

EBV testing was carried out over a period of 49 hours for the second anodized Be sample, evaluating the effects of O_2, N_2, and CO_2. (Figure 2) The restorative effects of these gases at a pressure of approximately 5×10^{-6} to 7×10^{-6} Torr were all positive. δ max increased typically from 2.4 to 3.5 for O_2, and from 2.4 to 3.2 for both N_2 and CO_2. The sequence of the evaluations were O_2, N_2, N_2, CO_2, and O_2. The last O_2 treatment at hour 47 showed similar results to the initial O_2 treatment at hour 5.5. Between each gas treatment the previous gas was pumped away to a residual gas pressure of approximately 1×10^{-8} Torr, and the secondary-emission ratio was degraded by electron bombardment at 0.75 A/cm^2. It thus appears that O_2, N_2, and CO_2 have a significant beneficial effect on the δ of an anodized Be surface.

2.1.3 Beryllium

A naturally oxidized Be surface (oxidation due to exposure to air at room temperature) was evaluated in the EBV for 58 hours (Figure 3).

Beneficial effects were noted for O_2, N_2, and CO_2, all at the same pressure of 6×10^{-6} Torr. The sequence of gas treatments was O_2, N_2, O_2, CO_2, O_2. All showed significant effects but O_2 was perhaps the most

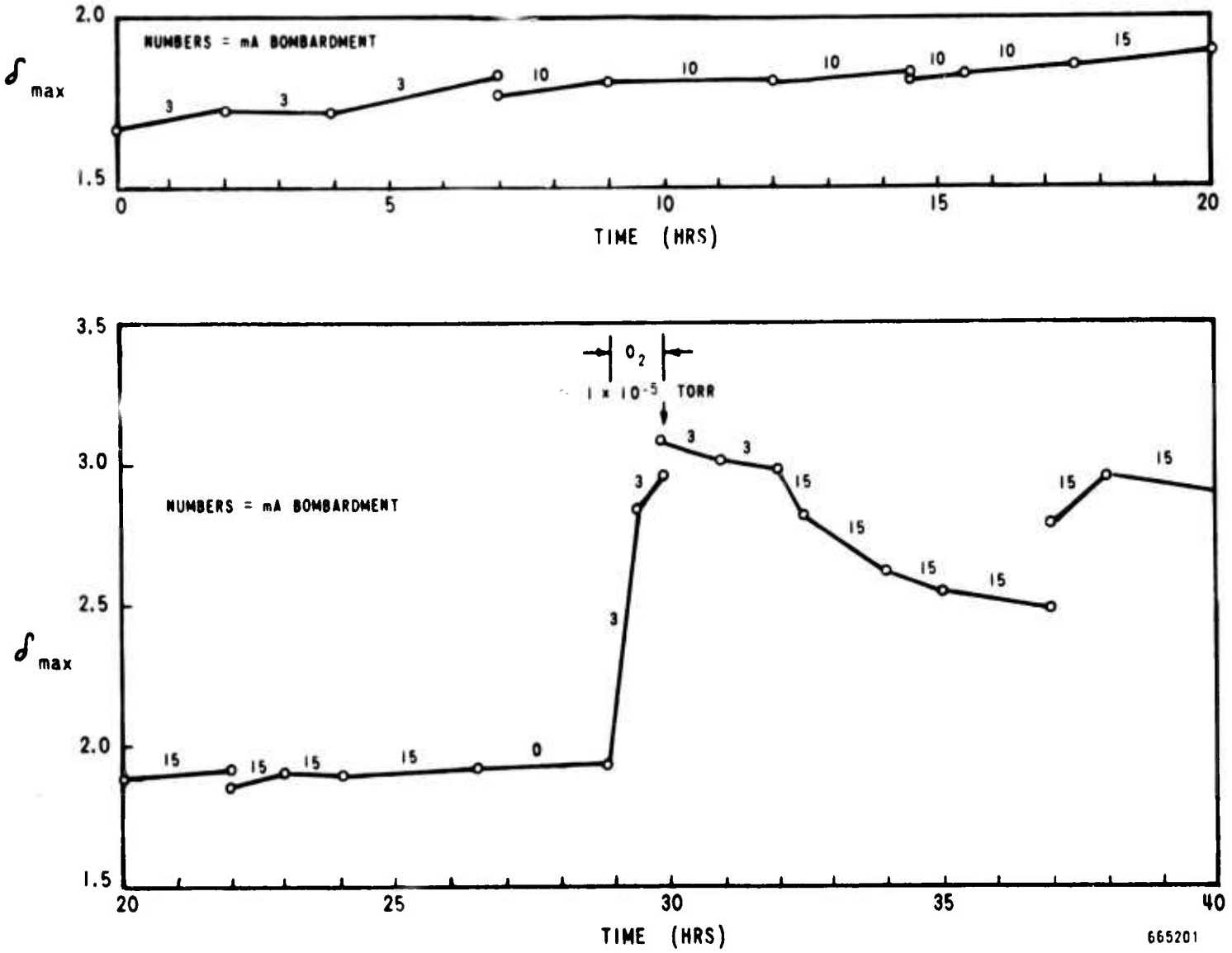


Figure 1, Sheet 1. δ_{max} vs EBV Time for 300Å Anodized Beryllium

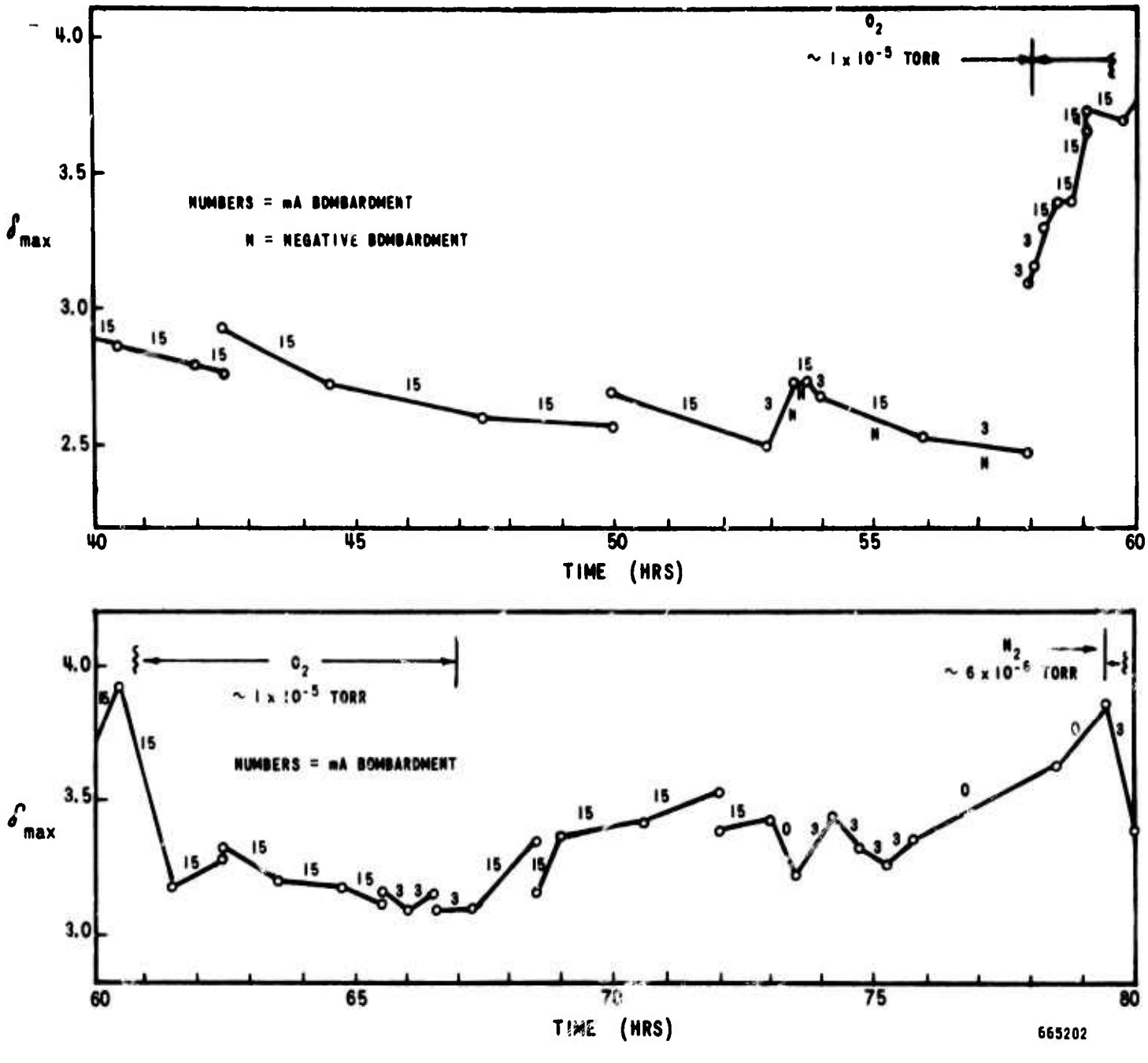


Figure 1, Sheet 2. δ_{max} vs EBV Time for 300Å Anodized Beryllium

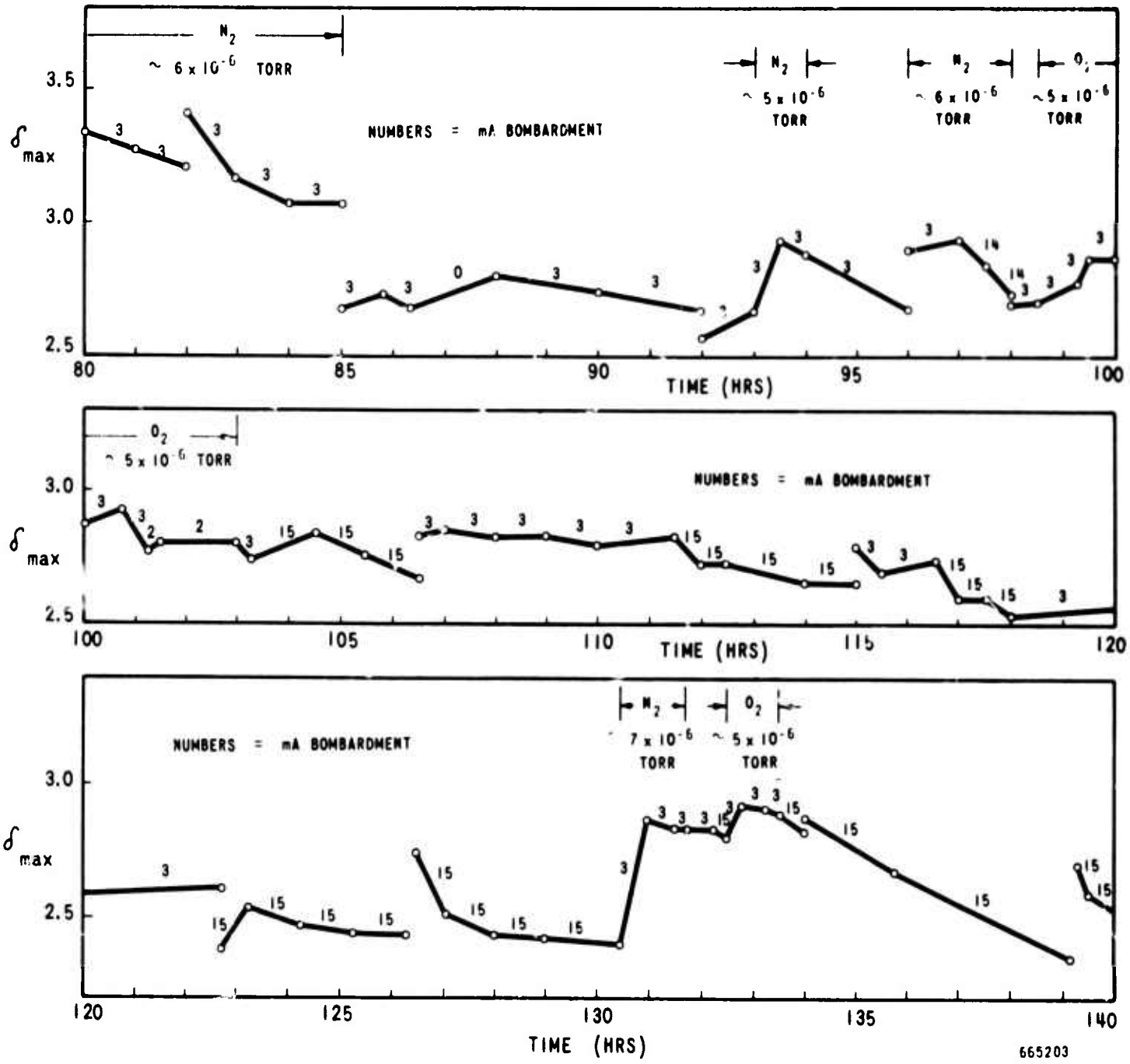


Figure 1, Sheet 3. δ_{max} vs EBV Time for 300Å Anodized Beryllium

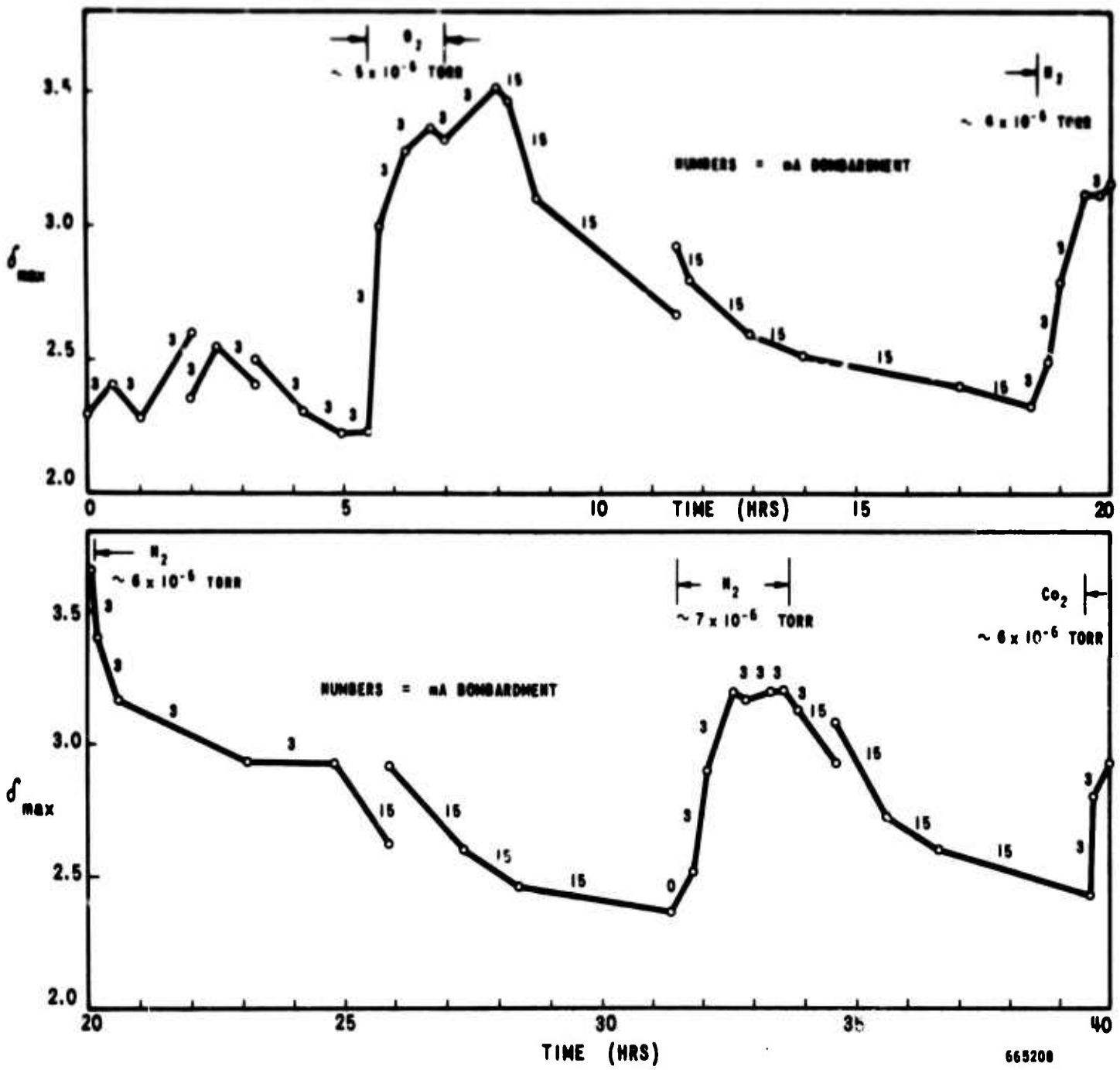


Figure 2, Sheet 1, δ_{max} vs EBV Time for 300Å Anodized Beryllium

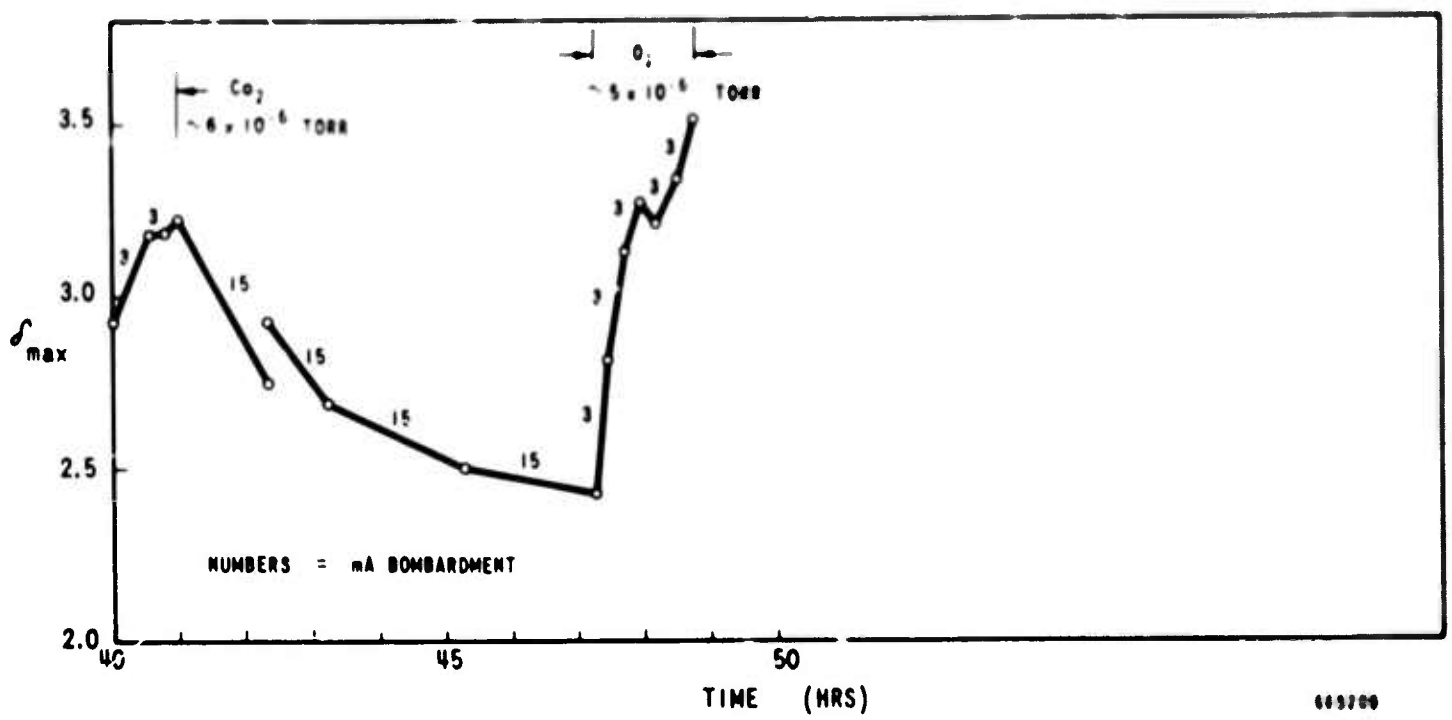


Figure 2, Sheet 2. δ_{max} vs EBV Time for 300Å Anodized Beryllium

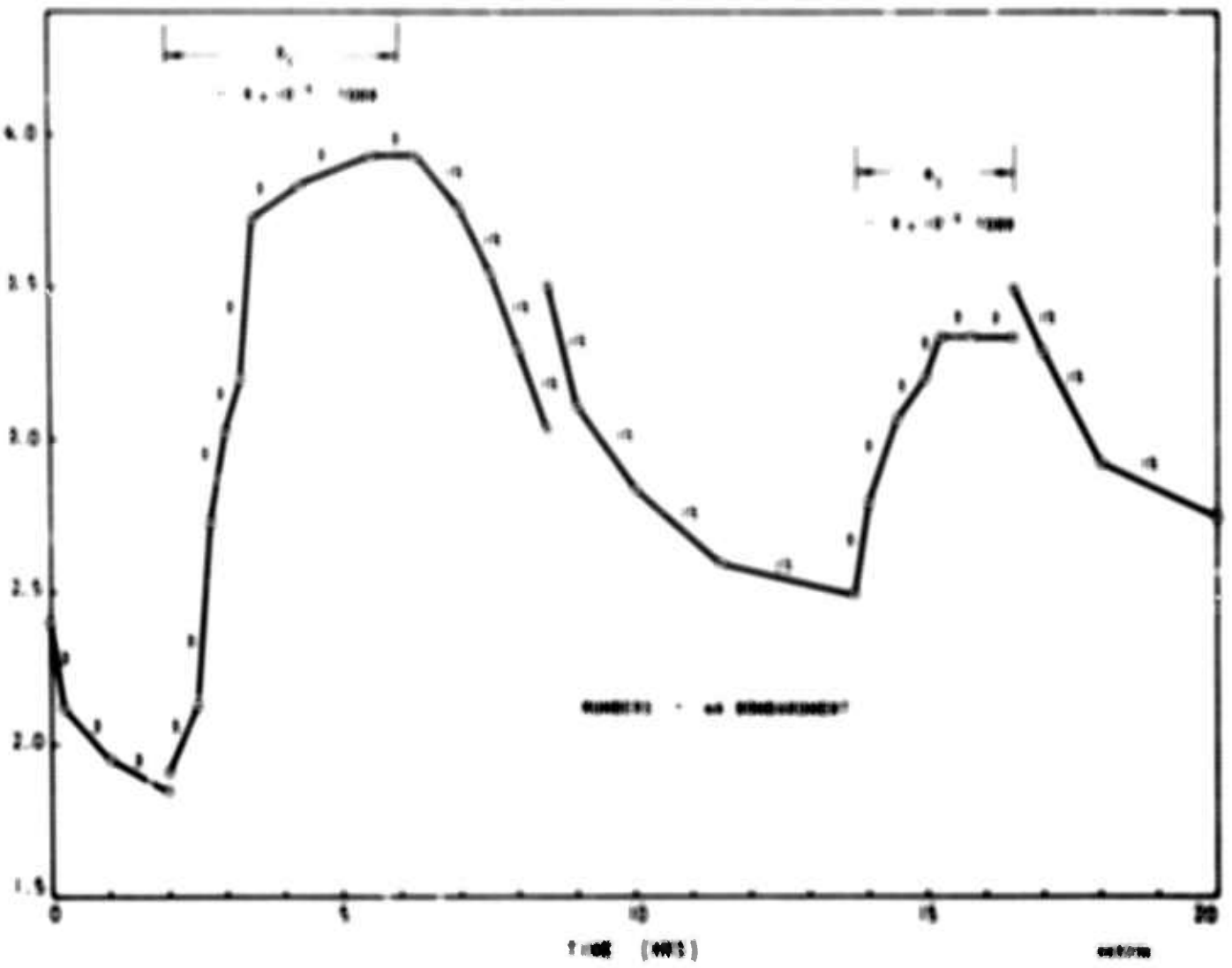


Figure 1. Sheet 1. δ_{max} vs EBV Time for Naturally Oxidised Beryllium

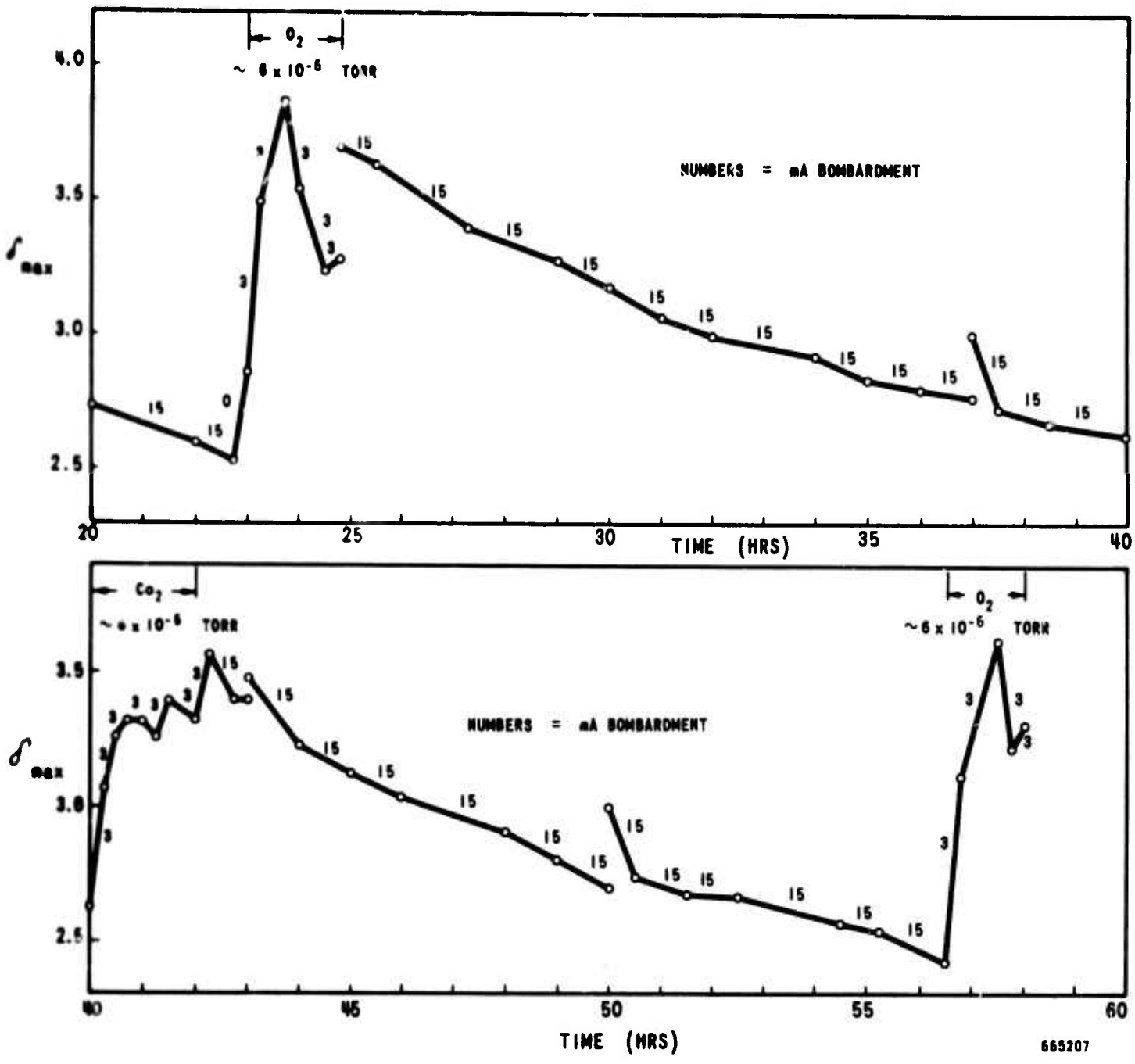


Figure 3, Sheet 2, δ_{max} vs EBV Time for Naturally Oxidized Beryllium

effective. Typically, the gas treatment increased δ max from approximately 2.5 to between 3.5 and 4.0. After several gas treatments it appeared that the rate of degradation of δ due to 0.75 A/cm^2 electron bombardment had slowed down. Note hours 25 to 40 and also 43 to 56.

2.1.4 300Å Al_2O_3 Film on Molybdenum

During a 41-hour period of EBV evaluation the sample was exposed to O_2, N_2, and CO_2 (Figure 4). The initial effect of O_2 at 6×10^{-6} Torr pressure was to increase δ max from 2 to 4.2. Subsequent degradation of δ max to 2.6 due to 0.75 A/cm^2 electron bombardment was followed by an unsuccessful attempt to increase δ due to N_2 at 6×10^{-6} Torr. Following this, an O_2 treatment at 6×10^{-6} Torr did increase δ max from 2.6 to 3.05. Although this was smaller than the initial effect, the N_2 effect was decidedly much smaller than that of O_2.

Subsequent gas treatments caused only small effects with δ max varying between 2.3 and 2.75. The results during this latter portion of the EBV evaluation (hours 23 to 42) are deemed inconclusive since the "condition" of the sample was not "normal" as evidenced by the lack of a strong, positive O_2 response.

3. PHASE B - CFA TESTING

3.1 QKS1397 Test Vehicle

3.1.1 Model No. 8C. Cathode emission life-test evaluation continued on Model 8C during the report period, at a cathode-pulsed modulation test station. This model features a cathode with 0.5-mil Al coating on an OFHC copper base.

Initially, the evaluation was conducted without the use of oxygen-assistance to determine the rate of emission deterioration. The operating level chosen was as follows:

Du	=	0.0017
fo	=	3.3 GHz
P_{in}	=	63 kW
Pout	=	700 kW
e_b	=	30 kV
i_b	=	45 A
B	=	3000 gauss

Peak Cathode current density = 2.8A/cm^2

Avg. Cathode current density = 9.8 mA/cm^2

In Figure 5, the peak current obtained is shown as a function of time for the life-test duration. The plot shows a gradual decrease in the peak current for the first hour and 40 minutes. The test vehicle was shut down for

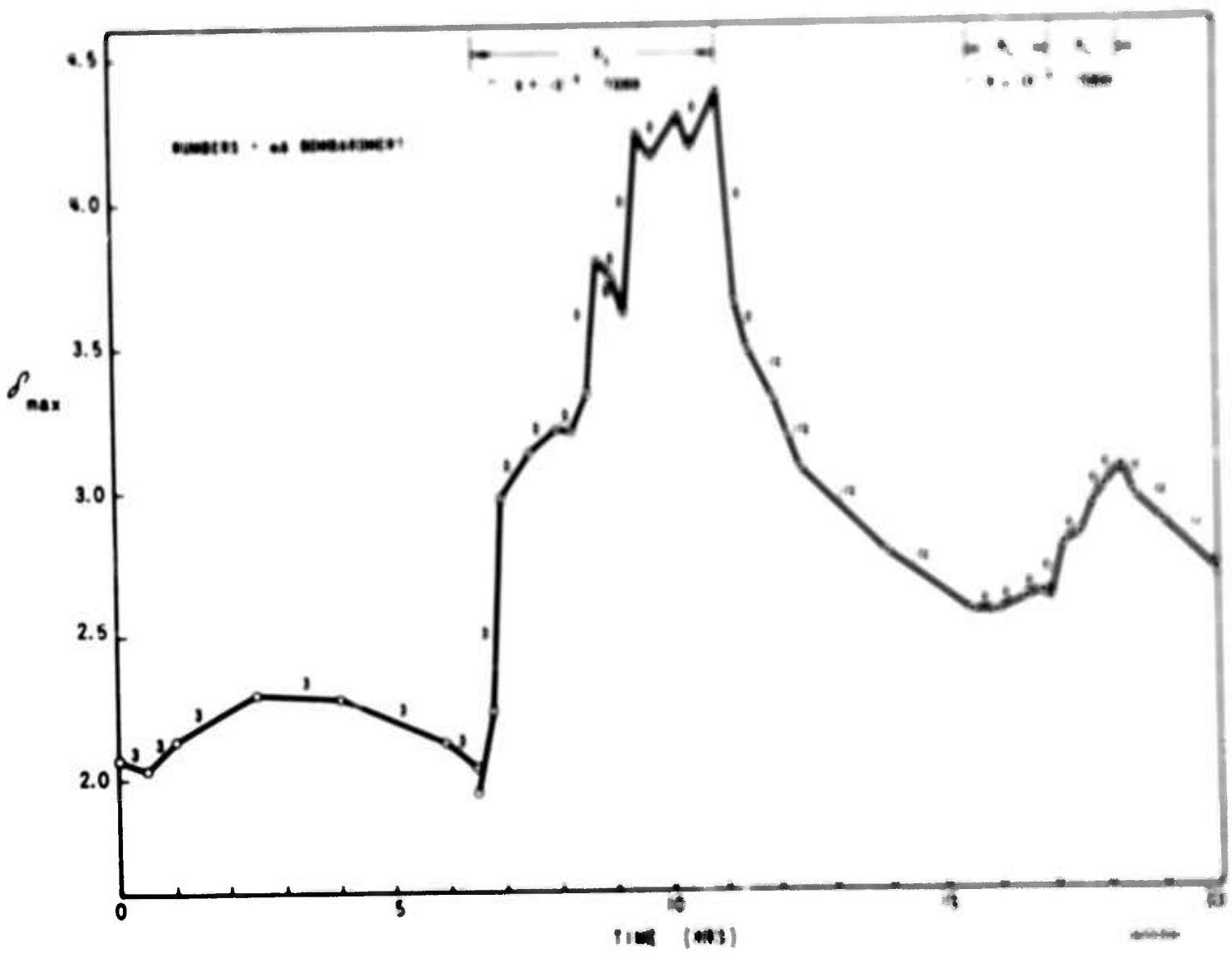
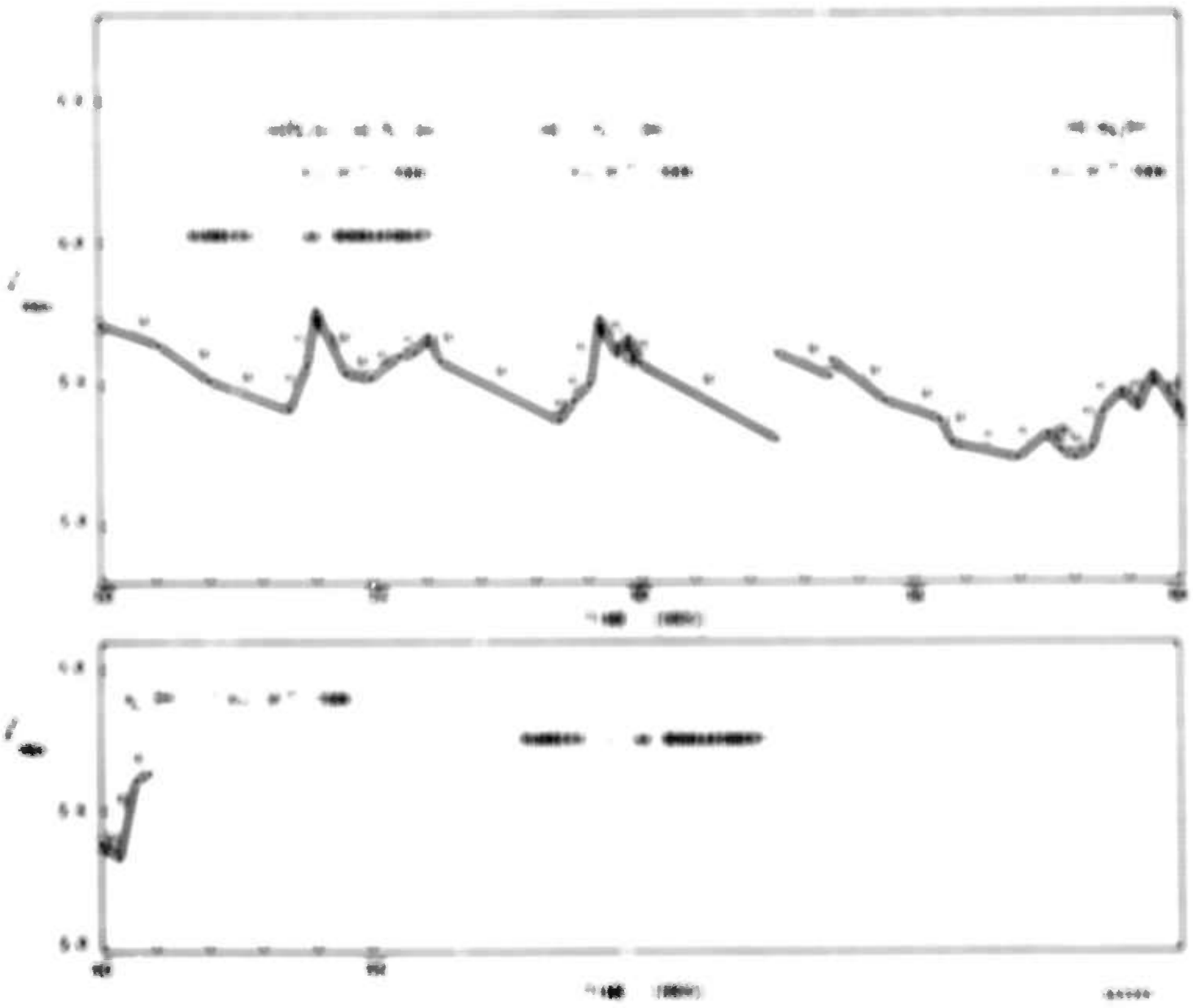
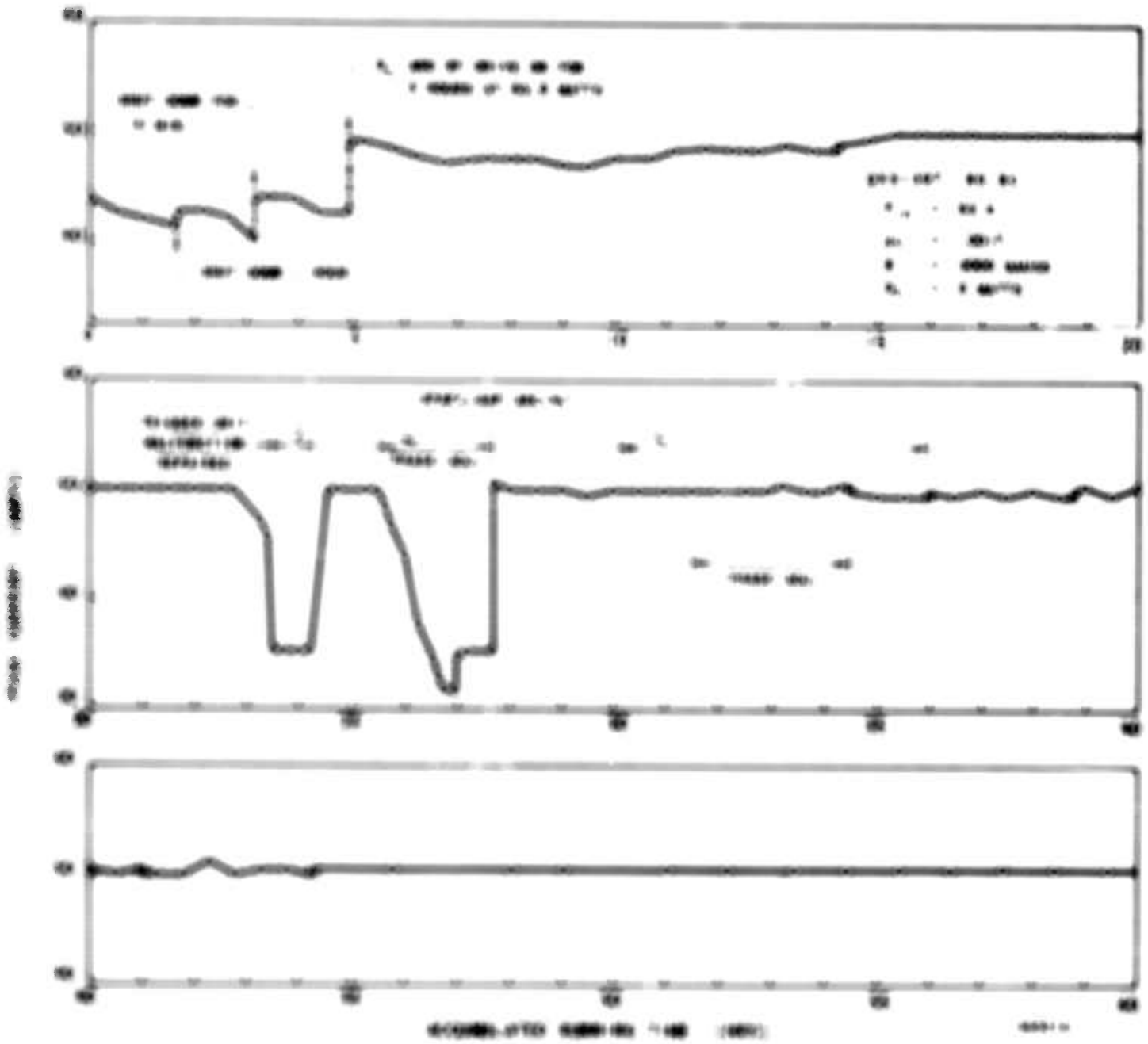


Figure 4. Sheet 1. δ_{max} vs EBV Time for 300Å Al_2O_3 on Molybdenum





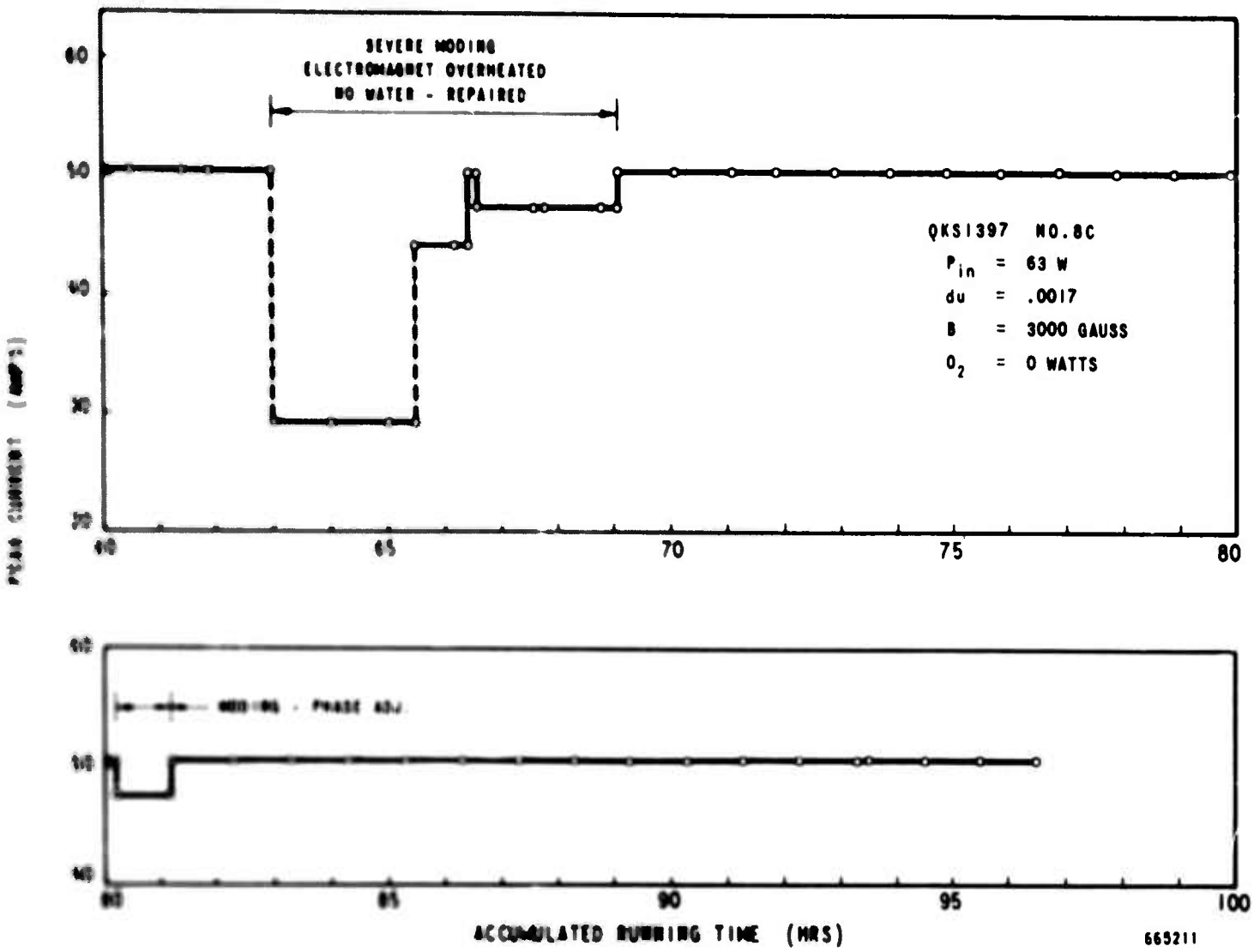


Figure 5, Sheet 2. QKS1397 No. 8C -
Running Time vs Peak Current

one hour, and - when restarted - the peak current was slightly higher than before. The peak current again gradually decreased for one hour and 30 minutes, and after a shutdown period of 15 minutes, the peak current was higher than before shutdown. For the next one hour and 45 minutes the peak emission gradually decreased.

At this time the oxygen dispenser was activated at 63 watts of heater power for five hours. No pulsed high voltage was applied to the test vehicle, but rf drive power was present throughout. At the end of the five-hour period, the life-test evaluation resumed without the use of oxygen assistance.

Continuous operation was maintained at 47 to 50 amperes (intentionally limited to 50 amperes) for 18 hours. A trigger unit malfunction caused the test vehicle to arc at this point, with resultant loss of emission. After repair and proper phasing adjustments the peak emission was re-established at its former level.

Stable operation was maintained in this manner for 35 hours. Severe moding was now observed due to an excessively warm electromagnet (lack of coolant). The electromagnet coolant flow was re-established, and the peak emission recovered to 50 amperes. Stable operation was maintained for 27.5 hours. At this time a vacuum leak developed in the tube, terminating further evaluation. The test vehicle has been repaired and is now awaiting available modulator space for continuation of life-test evaluation.

3.1.2 Test of QKS1194 with Impregnated Tungsten Emitter

The QKS1194 cold-cathode test vehicle was placed in the final stage amplifier position of a high-power, S-band chain system. The tube was operated at the set of operating conditions established earlier and tabulated below:

e_b	(anode voltage-cathode pulsed)	46 kV
I_b	(average anode current)	650 mA
i_b	(peak anode current)	36.1 A
t_p	(pulse duration)	80 μsec
Du	(duty factor)	.018
P_o	(average output power)	22.5 kW
p_o	(peak output power)	1.25 MW
Gain		13 dB
Peak Cathode Current Density		1.6 A/cm^2
Avg-Cathode Current Density		29.1 mA/cm^2

The tube is now operating continuously around the clock and has accumulated over 150 hours at the established set of conditions. Operation is smooth and problem-free as evidenced by more than 60 hours of performance without a kick-out or shutoff. Low-gauss emission-current-boundary data

have been repeated every 50 hours and indicate no change in cold-cathode emission.

Operation will continue until approximately 500 test hours have been accumulated. Low-gauss emission-current-boundary data will be fully evaluated to determine if the life-testing environment has produced any emission enhancement or deterioration, and graphed data will be presented in a future report.

4. CONCLUSIONS

4.1 Phase A - Materials Evaluation

a. Both the 300Å anodized Be as well as the naturally oxidized Be samples showed significant increases in δ_{max} as a result of O_2, N_2, and CO_2 treatments. Typical increase of δ_{max} was from 2.5 to 3.5 using a gas pressure of approximately 5×10^{-6} Torr with a residual pressure of 1×10^{-8} Torr.

b. A sample of 300Å Al_2O_3 on Mo showed a significantly smaller N_2 effect than for O_2 in increasing δ_{max}.

4.2 Phase B - CFA Testing

Operation of the QKS1397 CFA test vehicle for more than 330 hours, the last 100 hours during the present report period, has shown that the available emission from a deposited-aluminum cold cathode appears to have stabilized near 50 amperes (2.8 A/cm^2 pk, 4.8 mA/cm^2 avg.) at 0.0017 duty factor. Continuous use of the oxygen dispenser for maintaining the cathode emission was not required during the last 100-hour period; instead, prior to the test run, the cathode emitter was conditioned for five hours with oxygen and rf drive power alone.

Stable operation of the QKS1194 CFA test vehicle for over 150 hours at 1.6 A/cm^2 peak, 29.1 mA/cm^2 avg, can be realized without use of any oxygen dispenser operation.

5. PROGRAM FOR NEXT INTERVAL

5.1 Phase A

a. Continue evaluating effect of other gases such as H_2, CO_2, N_2 and CO on Al and Be cold cathodes in the EBV.

b. Evaluate both unprocessed and optimally oxidized Ag-Mg and Be-Cu samples in the EBV.

5.2 Phase B

a. Continue operating test of QKS1397 Model 8C with Al on Cu cathode.

b. Rebuild the QKS1397 test vehicle with an impregnated-tungsten cathode.

c. Continue operating test of QKS1194 with impregnated tungsten cathode.

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